GEOPHYSICAL MODEL OF CREEDE, COMSTOCK, SADO, GOLDFIELD AND RELATED EPITHERMAL PRECIOUS METAL DEPOSITS

COX AND SINGER MODELS:
Creede epithermal vein (25b),
Comstock epithermal vein (25c),
Sado epithermal veins (25d),
and quartz-alunite Au-Ag (25e).

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ŽModels with related geophysical characteristics (Cox and Singer, 1986): Au-Ag-Te veins (22b), Polymetallic veins (22c), Hot springs Au-Ag (25a).

A. Geologic setting (Cox and Singer, 1986)

ŽContinental, usually mid-Tertiary, felsic volcanic centers.
ŽFaulted, fractured, and brecciated, andesitic to rhyolitic lavas and tuffs, hypabyssal, porphyritic dacite to quartz monzonite intrusions.
•Deposits occur in the edifice of volcanic morphologic features, often near edge of volcanic center, or above or peripheral to intrusions.
•Commonly associated with resurgent caldera structural boundaries.
ŽCommodities: Au, Ag, Cu, Pb, Zn

B. Geologic Environment Definition

Gravity lows are common over thick silicic volcanic rock sequences and caldrons. The presence of a deep, low-density granitic batholith within the basement rocks may contribute to the gravity low (Ratté and others, 1979; Plouff and Pakiser, 1972, Steven and Eaton, 1975).

Short-wavelength magnetic anomalies are common over volcanic terranes because of variable magnetizations and polarizations. This pattern may contrast with an area of moderate to intense alteration that will display a longer-wavelength low, often linear in the case of vein systems, caused by destruction of magnetite. Local highs may be associated with hypabyssal intrusions (Ratté and others, 1979; Wynn and Bhattacharyya, 1977; Irvine and Smith, 1990, Doyle, 1990).

Radiometric highs may occur from regional potassic enrichment associated with volcanism. Regional alteration patterns may also be apparent in multi-spectral remote sensing (Marsh and McKeon, 1983; Podwysocki and others, 1983; Duval, 1989; Watson, 1985).

Regional seismic sound velocity for volcanic sequences are low compared to basement rock. Seismic reflections are generally incoherent and noisy because of signal scatter by volcanic layers and structure (Hoffman and Mooney, 1984; McGovern, 1983).

Regional resistivity is generally low for weathered and altered andesitic to rhyolitic volcanic rocks as compared to high resistivity typical of buried intrusions or uplifted basement or carbonate sedimentary rocks (Frischknecht and others, 1986; Long, 1985; Senterfit and Klein, 1991).

C. Deposit Definition

There are no consistent geophysical signatures to directly identify epithermal vein mineralization. However, several geophysical characteristics are diagnostic of favorable structures and alteration. These characteristics are best measured using closely spaced ground measurements (Irvine and Smith, 1990; Allis, 1990; Doyle, 1990; Johnson and Fujita, 1985; Middleton and Campbell, 1979; Senterfit and Klein, 1992; Zonge and Hughes, 1991).

Gravity highs will be caused by felsic intrusions within flow or tuff sequences, by structural highs of basement or carbonate rocks within the volcanic sequence, or by silicification of otherwise relatively low-density volcanic rock. Weak, local lows may exist over zones of brecciation or fracturing. Weak, local highs may be found over dense silicic vein systems hosted by more porous volcanic rocks. On deposit-scale investigations, high-precision gravity to resolve anomalies of the order of 1 mgal (to 0.5 rarely) would be required (Irvine and Smith, 1990; Allis, 1990; Criss and others, 1985; Kleinhampl and others, 1975; Ratté and others, 1979; Locke and De Ronde,

1987) .

Magnetic lows will be associated with alteration; however, discriminating such lows from the background may be difficult on a deposit scale.

Radiometric anomalies are expected across epithermal veins because of potassic alteration, which is common in the upper levels of veins (Marsh and McKeonn, 1983; Pitkin and Long, 1977).

Resistivity highs flanked by resistivity lows are characteristic of a simple and idealized quartz-adularia vein system with associated argillic to propylitic alteration. However, there may be geologic structures and petrologic complications that distort this ideal picture. More generally, resistivity lows will be associated with: 1) sulfides when concentrated and connected at about 5-percent volume or more, 2) argillic alteration, and 3) increased porosity related to wet, open fractures and brecciation. Resistivity highs will be associated with zones of silicification, intrusion, or basement uplifts (Senterfit and Klein, 1992; Zonge and Hughes, 1990; Irvine and Smith, 1989; Allis, 1990; Doyle, 1990, Frischknecht and others, 1986).

High induced polarization (IP) will be associated where pyritization has developed (Zonge and Hughes, 1991).

D. **Size and Shape of deposit** (Buchanan, 1981; Heald and others, 1987):

Element	**Shape**	**Average Size (Range)**
Vein system, or district	lenticular, interlaced	3 km (l-9 km) width, 7 km (2-21 km) length, probably 2-4(?) km depth extent.
Ore deposit	lenticular, interlaced, discontinuous	width and length is highly variable, but a fraction (0.2?) of vein system; vertical extent of ore averages 500 m; paleodepths to initiation of ore (relative to original surface) is about 400 m (200 to 700 m).
Alteration halo	symmetric with the vein system; siphon shape in cross-section, narrowing with depth; capped with siliceous sinter that is often missing because of erosion.	width is of the order of 2 or 3 x the width of the vein system, roughly centered linearly on the vein system, wider on hanging wall if appreciable dip is present.

E. **Physical properties**

Bracketed values are averages. Source references are indexed with trailing letters. Queried values are guesses.

Property [units]	**Deposit** [silicic - potassic vein]	**Alteration** A: argillic (illite-kaolin) P: propylitic (chlorite-minor kaolin)	**Volcanic host**

1. Density (gm/cm^3)	quartzite 2.6[29]	?	rhyolite [2.5][29] andesite [2.7][29] tuffs 1.5-2.5[14]
2. Porosity (percent)	2-5?	5-20?	3-50[6,18] (fig.22)[18]
3. Suscepti-bility (cgs)	negligible?	negligible?	rhyolite [.3 x 10^{-3}][23,27]; undifferentiated Tertiary volcanic rocks: (Arizona) .05 x 10^{-3} - 5 x 10^{-3}, (northern Montana)[37,3] [0.7 x 10^{-3}]
4. Remanence (cgs-emu/cc)	negligible?	negligible?	undifferentiated Tertiary volcanic rocks: (Arizona): .005 x 10^{-3} - 100 x 10^{-3}, (northern Montana)[37,3] [11.1 X 10^{-3}]
5. Resistivity (ohm-m)	high; greater than 1,000?	A: low; less than 10? P: low; less than 100?	Tertiary volcanic rocks (Arizona): 20-2,000 [38]
6. Induced polarization (IP) (percent-frequency effect:PFE)		?	PFE > 10 with about 2 or 3-% disseminated sulfides[4]. Tertiary volcanic rocks (Arizona): < 5[4]
7. Seismic sound (Vp) velocity (km/s)	quartzite 5.37-5.63[6]	lower?	wet tuffs: 2.61-3.92[6]; rhyolite: [3:27] 2.94-4.90[6]; volcanic breccia: 4.22[6]; (measurements at 0.1 kb; anisotropy is high (17-26% in some rhyolites with >10 (measured 18-32%) porosity.

8. Radio-elements K (%) U, Th (ppm)	K: high? U, Th ?	K: high? U, Th, K?	moderate to low? U,Th ?

F. Remote sensing characteristics

In areas of low to moderate *cover,* remote sensing images in the visible and infrared bands can be processed to identify exposures of oxidized argillic alteration, and anomalous silicification, although there is considerable room for non-unique discriminations for moderate to low-spectral-resolution systems (Rowan and others, 1974, 1977; Podwysocki and others, 1983; Watson, 1985, Watson, 1990, Watson and Raines, 1990). The basis of such discrimination are the following:

a) In the visible through infrared wave-spectrum, ferric iron, water, and hydroxyl complexes have narrow (about 0.1 pm) and characteristic reflective minimums between 0.4 and 2.4 pm (Rowan and others, 1977).

b) Silica-rich assemblages have emissivity minimums near 8-10 **μm** (Watson and others, 1990).

c) These reflective and emissivity minimums can distinguished with moderate resolution (0.1 **μm)** airborne- or spacecraft spectral scanners.

There are often distinctive spectral waveforms for other minerals and mineral assemblages (Hunt, 1989), that require high-resolution (.01 to .001 pm), spectral scanners, currently available only on airborne systems (Watson and Raines, 1989).

G. General Comments

H. References

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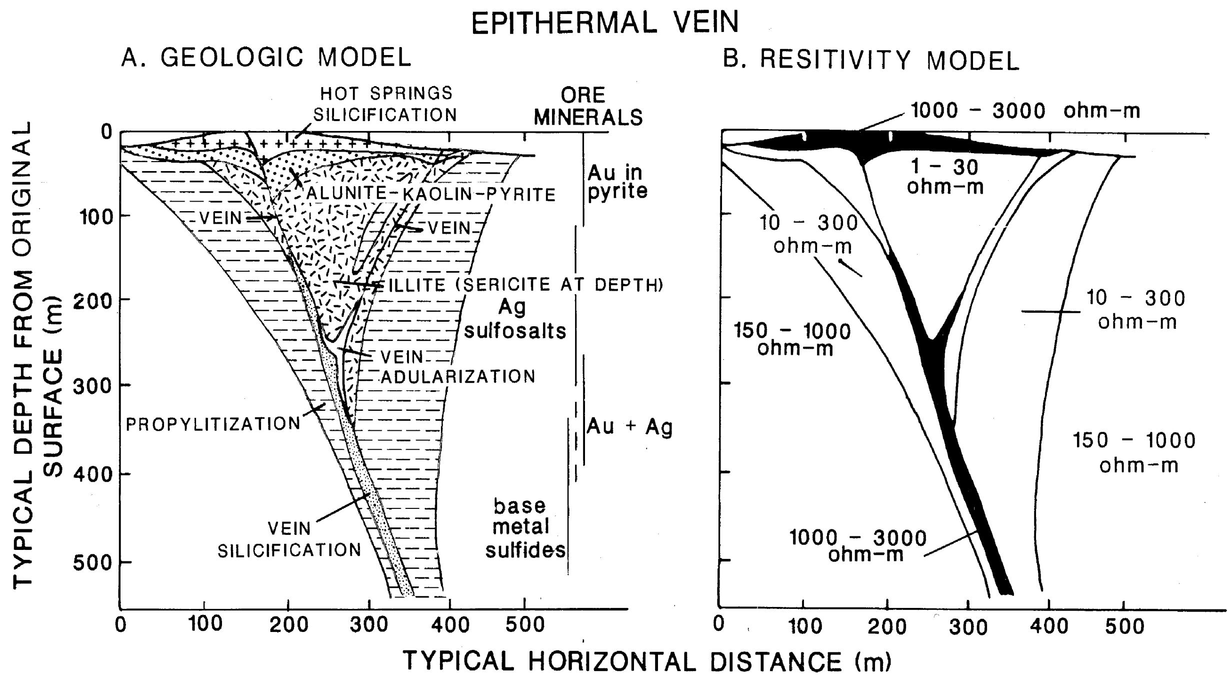

Fig. 1 — A) Conceptual model of alteration for an epithermal vein (adapted from Buchanan, 1981; Irvine and Smith, 1990); B) Inferred Electrical resistivity for the model shown in (A).

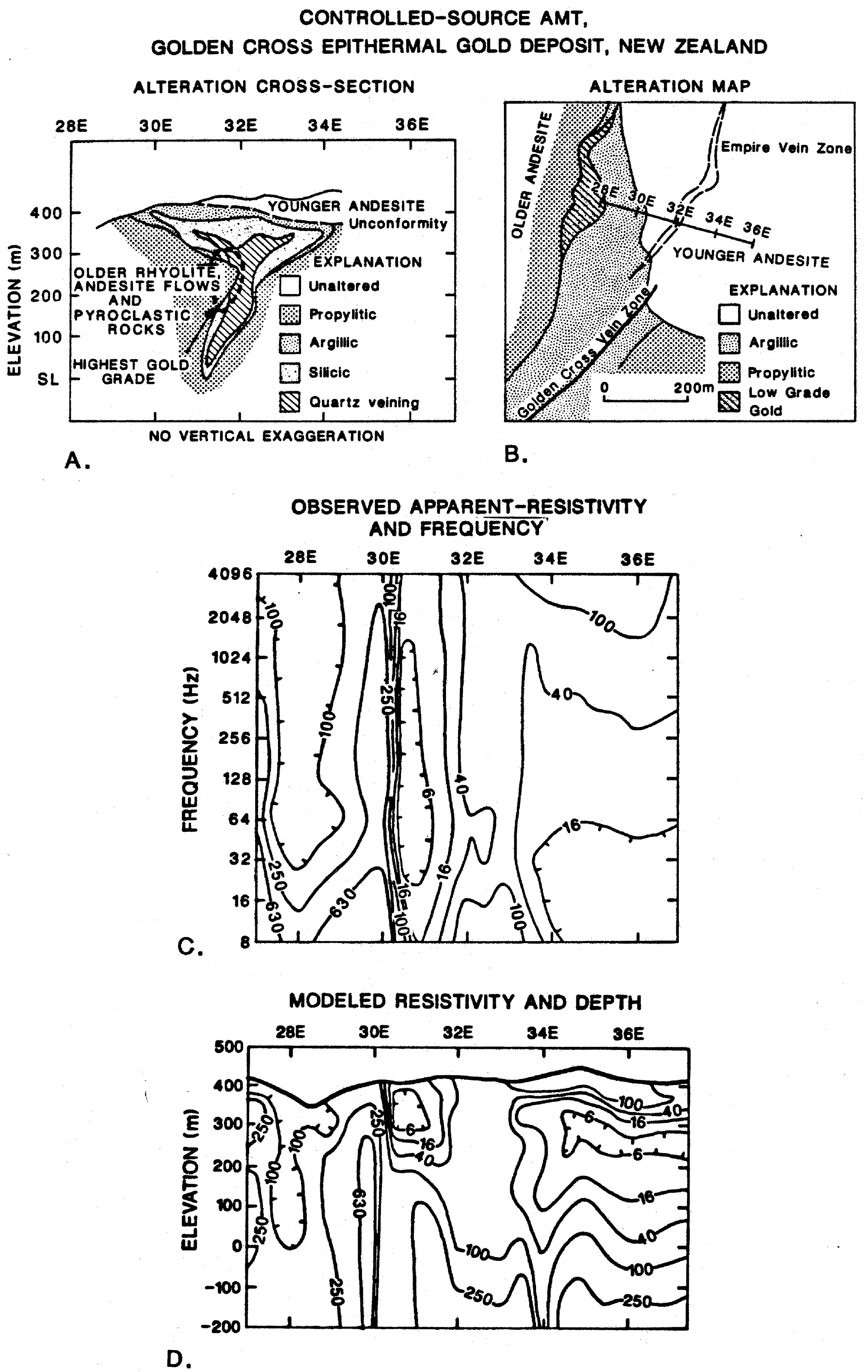

Fig. 2 — Electrical resistivity data from controlled source audio-magnetotelluric (CSAMT) data over an epithermal vein system on the northern coast of North Island, New Zealand (adapted from Zonge and Hughes, 1991). A) Simplified alteration map of survey area showing the location of electrical traverse. B) Simplified interpretation of the alteration and veining along the cross-section traversed. C) Electrical pseudo-section of apparent resistivity vs. frequency. D) Electrical section of resistivity vs. depth resulting from inversion of data. On (C), the high-resistivity (>250 ohm-m) silicified zone, bordered by anomalous lows (<100 ohm-m) forms a prominent vertical electrical structure. The andesitic to rhyolitic host rocks show resistivities varying from about 5 to 500 ohm-m.

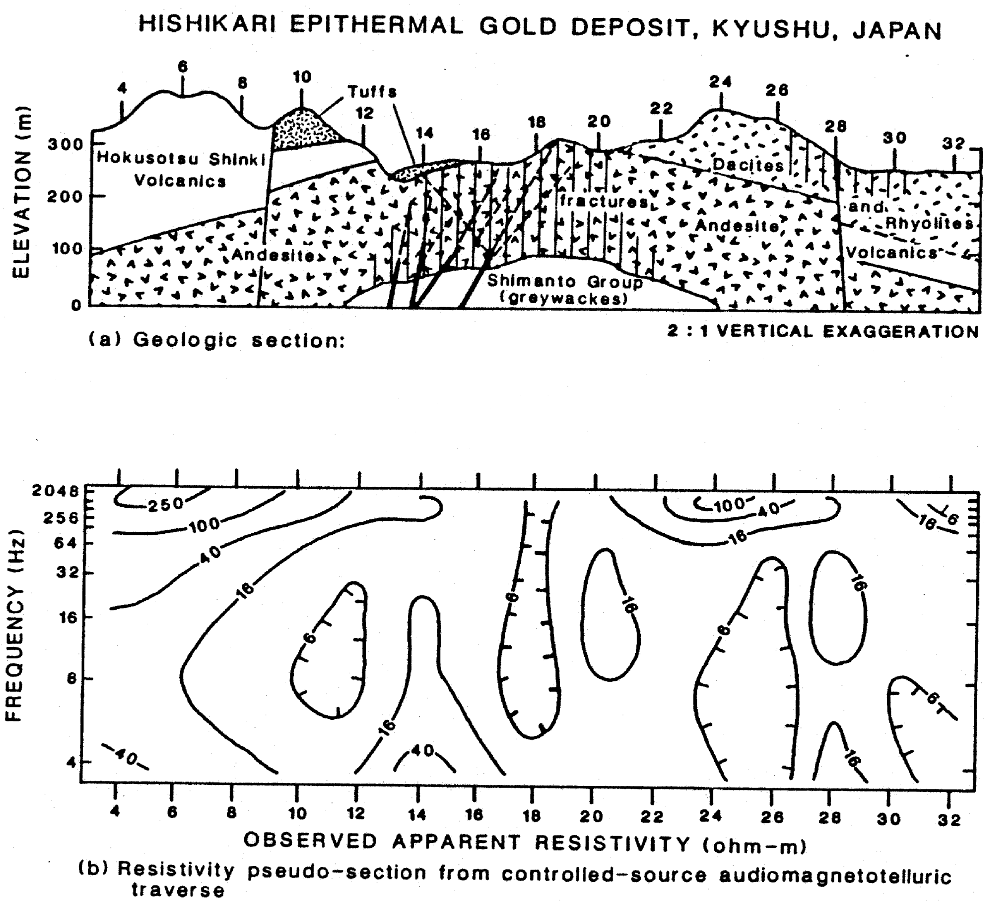

Fig. 3 — Electrical resistivity data from controlled source aduio-magnetotelluric (CSAMT) data over the Hishikari epithermal vein system in Kyushu, Japan (adapted from Zonge and Hughes, 1991). (A) Simplified geologic section across the deposit. B) Electric pseudo-section of apparent-resistivity versus frequency across the deposit. The Hishikari deposit is within an active geothermal system. Gold mineralization was found in veins in the Shimanto Group. The overall low resistivity is related to rock saturated with hot-water. Resistivity variations are associated with variable porosity and temperature, with the low resistivity under sounding 18 interpreted as a primary fracture system that continues into the mineralized vein system in the Shimanto Group (Zonge and Hughes, 1991, p. 797).